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Effectiveness of progressive resistance training for increasing maximal repetitive lifting capacity

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Abstract

The purpose of this study was to investigate the effects of 12 weeks of progressive resistance training on the performance of a high intensity repetitive lifting task. The repetitive lifting task consisted of lifting a 41 kg box to a chest high shelf as many times as possible in 10 min. Subjects were randomly assigned to a training (TR) or a control group (CT). The TR group (n=18) participated in progressive resistance training 3 times each week for 12 weeks. The CT group (n=7) was asked to maintain their current exercise habits which did not include progressive resistance training. Repetitive lifting task performance and one repetition maximum strength for box lift, bench press, deadlift and squat were recorded before and after progressive resistance training. Improvement in the strength of the training group was significantly greater ($p<.05$) than that of the CT group. The increase in strength was accompanied by greater change ($p<.05$) in repetitive lifting task performance for the training group (pre-test=79.1 lifts, post test=92.4 lifts) than the CT group (pre-test=84.9 lifts, post test=82.0 lifts). It is concluded that traditional progressive resistance training exercises are effective in improving performance of an occupational lifting task. Regular progressive resistance training can be particularly important in maintaining the effectiveness of manual workers in jobs that require high intensity lifting on an infrequent basis.

Keywords: Physical fitness; training; work; manual lifting;

Introduction

The frequency of lower back injury increases with the ratio of occupational lifting demands to the worker's maximum lifting strength (Chaffin 1974). It was also noted that less physically fit Naval personnel (Marcinik 1986) and firefighters (Cady et al. 1985; Doolittle and Kaiyala 1986) were more likely to suffer injuries than those who were more fit. Occupations requiring frequent manual materials handling involve considerable exercise, and novice lifters can be expected to improve performance during the first month of employment simply by performing the lifting task (Sharp and Legg 1988b, Genaidy et al. 1989). Once an acceptable level of performance is reached, day to day task performance does not provide sufficient overload to produce further increases in performance or to reduce the risk of job related injury. Many occupations involve high intensity repetitive lifting that occurs infrequently, such as emergency medicine, fire fighting and the military. The physical stress of infrequent high intensity lifting exercise may result in a higher injury rate and in diminished job performance of individuals who are less physically prepared.

Progressive resistance training is generally accepted as an effective adjunct to practice of technique for improving performance in sports. It follows then that the ideal training method for occupational lifting is performance of the lifting task, along with supplemental progressive resistance training. Such a training method has not commonly been

implemented in industrial settings. For workers who perform intense lifting only occasionally, the frequent performance of simulated job tasks, for the purpose of building physical strength would be prohibitively expensive for employers in terms of both resources and time. For example, U.S. Army soldiers participate in field training exercises with live ammunition for only a small percentage of their training time due to the risk of injury, as well as the cost. The Army's standard physical training programme is not designed to strengthen muscle groups specifically involved in occupational lifting. While some corporations provide employees with exercise facilities or discounted health club memberships, the goal is to improve health, with improvement in job performance as an indirect result. Equipment for task specific strength training is rarely available to industrial employees. A programme of progressive resistance training using carefully selected exercises may be a practical approach to strength training for occupations with infrequent heavy lifting requirements, particularly in the absence of task specific training tools.

Little information is available to show the effects of progressive resistance training on industrial repetitive lifting performance. Asfour et al. (1984) utilised progressive resistance box lifting and aerobic training and noted significant increases in strength, aerobic capacity and maximum box lift following 6 weeks of training. Sharp and Legg (1988b) implemented a psychophysical training programme in which subjects were asked to adjust the box mass to the maximum they could lift for one hour at a rate of 6

lifts·min^{-1}. Training consisted of lifting a self-selected load for two 15 minute sessions, 5 days per week for 4 weeks. Psychophysical training was shown to increase the box mass lifted for one hour. Genaidy et al. (1988) achieved a twofold increase in carrying endurance time after a 2-1/2 week training programme consisting of carrying a 20 kg load 4 m at a frequency of 8 boxes/min. As the greatest improvements in performance are observed when the training and testing modes are identical (Fleck and Kraemer, 1987) it should be noted that all three training studies utilised the same equipment for testing and training. The effect of a programme of traditional progressive resistance training exercises on occupational repetitive lifting performance has not been examined. The purpose of this study was to determine whether 12 weeks of progressive resistance training is an effective means of improving performance of an occupational lifting task.

2. Methods and Procedures

2.1 Subjects.

Twenty five males with minimal manual materials handling experience were recruited to participate. Subjects were randomly assigned to one of two training groups or to the control group. Subjects were briefed on the requirements and hazards involved in the study then read and signed an informed consent statement. None of the volunteers had been involved in a resistance training programme within the previous 6 months and all subjects were instructed not to begin any new training procedures.

2.2 Schedule.

Lifting familiarization, profiling of subjects and measurement of maximal repetitive lifting capacity took place during the three weeks preceding the twelve week training programme. The profiling and maximal repetitive lifting capacity measurements were repeated at weeks four and eight of the training programme and following the twelfth week of training.

2.3 Repetitive lifting task.

The repetitive lifting task (10 min lift) was designed to simulate the resupply of a U.S. Army 155 mm Howitzer. The resupply is one of the most physically demanding tasks the field artillery soldier performs and elicits the highest heart rates (Patton et al. 1987). The crews move up to 134 projectiles weighing 41 kg each from the supply vehicle to the Howitzer in 10 minutes or less (Vederhyde 1989). The dependent variable for maximal repetitive lifting capacity was the total number of lifts of a 41 kg box completed in 10 minutes. A floor to chest level lift was selected to involve the upper body, and remove the advantage tall subjects have when using an absolute lifting height. The task was performed on a repetitive lifting machine which lowered the load each time it was lifted (Teves et al. 1987). Oxygen uptake, heart rate and lift rate were recorded continuously. Blood lactate was measured before and 5 min after lifting exercise. Subjects were instructed to develop an optimal pacing strategy in order to complete as many lifts as possible during the ten minute test. A straight back bent legs lifting technique was encouraged, but not required. Subjects performed two to three pre-training 10 minute lift tests during the initial three week

period. In no case was performance on the third pre-training 10 min lift task significantly better than on the second. The intraclass reliability coefficient was .97 for three trials and .93 for two. The second 10 min lift test was selected as the pre-training measure.

2.3 Subject Profiling.

The following determinations were made:

(1) Repetitive lifting maximal oxygen uptake ($\dot{V}O_2max$) was measured to evaluate the aerobic fitness of the subjects and to describe the relative exercise intensity (percentage $\dot{V}O_2max$) during the 10 min lift task. Procedures were identical to those previously reported (Sharp et al. 1988a), except that the lifting height was chest level, to equate with the 10 min lift task.

(2) One repetition maximum strength determinations were made for bench press, squat, deadlift and box lift. Maximum box lift was the heaviest load lifted to a chest high-shelf in a box similar to that used during the repetitive lifting task (Sharp & Legg 1988b).

(3) Body composition was estimated using the hydrostatic weighing method (Fitzgerald et al. 1987; Siri 1961). Residual lung volume was measured just prior to underwater weighing using the closed circuit oxygen rebreathing technique (Wilmore et al. 1980).

2.5 Training programmes.

The experimental subjects were split into two groups and participated in 12 week progressive resistance training programmes. Both groups trained

three days per week (Monday, Wednesday and Friday) and executed ten exercises in a random order. The free weight exercises used were bench press, deadlift, squat, bent knee sit-ups while holding dumbells, high pulls (rapidly raise weighted bar from floor to chest level and immediately lower bar to floor) and standing bent arm lateral dumbell raises (flys). Exercises performed on a Universal Gym apparatus were seated rowing, standing shoulder shrugs, standing military press, and hanging leg raises. The weight selected was the maximum that would allow the subject to complete the required number of repetitions for that set. If more than the required number of repetitions were completed, the weight was increased for the following set. All workouts were preceded and followed by stretching. The full rest programme (n=8) was designed with sufficient rest between exercises. To provide variation, recommended for the fastest improvement (Stone et al. 1981), the number of repetitions per exercise set was varied randomly within weeks from 3-5, 6-8 and 10-12. Three to five sets of each exercise were executed with 2 min rest between each set and exercise. The short rest program (n=10) was designed to increase lactate tolerance through the use of shorter rest periods. The short rest group completed 3 sets of 10-12 repetitions, with 30, 60 or 90 sec rest between sets and 1 min rest between each exercise. Each of the rest period variations were performed once each week in random order. The control group (n=7) was asked to continue their current level of aerobic training and calisthenics, and did not participate in a progressive resistance training programme.

2.6 Statistical analysis.

Repeated measures analysis of variance with an alpha of .05 was used to examine group differences in pre- to post training changes in lifting performance and profiling measures. Profiling measures were correlated with maximum repetitive lifting capacity to examine the relative importance of various fitness components in performing the 10 min lift task.

3. Results and Discussion

3.1 Training group comparison.

No significant differences were identified between the two progressive resistance training groups in pre- to post training changes in 10 min lift task performance or profiling variables. As expected, the short rest workout produced a significantly greater increase in post-workout blood lactate (8.9 ± 2.9 mmoles$\cdot l^{-1}$) than did the full rest workout (4.4 ± 2.2 mmoles$\cdot l^{-1}$). The short rest programme, however, did not result in a greater tolerance for blood lactate during the 10 min lift task. No significant difference was detected between the training groups in the increase in blood lactate due to the 10 min lift task following 12 weeks of training (short rest=10.8 ± 1.7 mmoles$\cdot l^{-1}$, full rest=11.9 ± 2.5 mmoles$\cdot l^{-1}$).

In order to reach exhaustion at the end of a 3-5 repetition set (full rest programme), heavier loads must be lifted than during a 10-12 repetition set (short rest programme). Lifting 3-5 repetition loads did not result in significantly greater increases in any of the strength determinations in the full rest group as compared to the short rest group. The total weight moved

(load (kg) x repetitions completed) during 12 weeks of progressive resistance training was not significantly different between groups. The full rest group moved 36,586 kg and the short rest group moved 35,582 kg during the 12 week training period, (p=.73). As no significant differences were identified between groups, there is no justification for identifying one programme as superior. It is hypothesised that programme similarities in weight moved and exercises used were more important than the differences in RM load and rest period. Therefore, in designing a training programme length of rest periods and number of repetitions per set can be based on practical constraints. For example, if time is limited, the short rest programme can be completed in a shorter time period. If a large number of people use the training equipment simultaneously, the slower paced full rest programme would accommodate several people per training station with a minimal safety risk.

Because no differences were identified between the two training groups, the data were collapsed and treated as one group. The mean ± standard deviation for age and height of the two groups was 24.6 ± 5.3 years and 178.6 ± 5.1 cm, respectively, for the control group and 18.9 ± 1.1 years and 175.7 ± 7.2 cm, respectively, for the training group.

3.1 Body composition.

Pre- to post test measures of body composition are listed in table 1. Twelve weeks of progressive resistance training resulted in a greater increase in body weight and fat free mass in the training group than in the control

group. The training group mean increase of 3.7 kg body mass was composed of 2.6 kg fat free mass and 1.1 kg body fat. The net gain of 0.6 kg body weight in the control group consisted of a mean gain of 0.9 kg of fat free mass and mean loss of 0.3 kg of body fat. The pre to post training percentage change in kilograms of body fat was significantly greater in the training group than the control group. A review of prior studies indicated that a short term progressive resistance training programme generally produces a decrease in body fat and an increase in fat free mass, with no net change in body weight (Fleck and Kraemer 1987). The progressive resistance training group increased body fat content as well as fat free mass. Since diet was not controlled, it is possible that the training group increased their food intake disproportionally during the training programme and this resulted in a net gain in body weight.

3.2 Maximal aerobic capacity.

Pre-training repetitive lifting $\dot{V}O_2max$ was 53.5 ± 6.5 ml·kg·min^{-1} and 53.7 ± 6.7 ml·kg·min^{-1} for the training and control groups, respectively. There was a decrease following training of 3.8 ± 4.4 ml·kg·min^{-1} in the training group and 4.6 ± 5.8 ml·kg·min^{-1} in the control group, but this decrease was not significantly different between groups. Gettman and Pollock (1981) reported an average increase of 5% in aerobic capacity following 10-20 weeks of circuit weight training. While the short rest training programme was similar to circuit weight training, it did not produce an increase in repetitive lifting $\dot{V}O_2max$. The mean treadmill $\dot{V}O_2max$ for comparable males is

approximately 50 ml·kg·min^{-1} (Vogel et al. 1986). Since treadmill $\dot{V}O_2max$ averages 12% higher than repetitive lifting $\dot{V}O_2max$ (Sharp et al. 1988), an estimate of treadmill $\dot{V}O_2max$ would be 60 ml·kg·min^{-1}, which is a high initial level of aerobic fitness. All test subjects were instructed to maintain their current level of aerobic training, but this was not monitored. Therefore, the decrease in $\dot{V}O_2max$ experienced by both groups may be the result of a decrease in aerobic training.

3.3 Strength determinations.

Increases in strength were examined to evaluate the effectiveness of the progressive resistance training programme. The strength determinations over time, and the mean percentage change pre to post training are presented in table 2. The training group increases in strength were significantly greater than the control group changes for all strength determinations as illustrated in figure 1. The percentage increases in the training group ranged from 19.8% on the deadlift to 34.6% on the squat and were similar to those observed in other progressive resistance training studies of similar length and intensity (Atha 1981; Fleck and Kraemer 1987). The control group changes ranged from -1.6% on bench press to 10.1% on the box lift. These nominal increases in strength were probably due to improved lifting technique, rather than an increase in muscular strength. All subjects had an opportunity to improve box lifting technique monthly while performing the 10 min lift task and repetitive lifting $\dot{V}O_2max$ test. The control group increased on only those lifts involving the lower body, with the greatest

percentage increase attained on the task specific box lift. No change was observed in the control group strength for the bench press, a lift familiar to all subjects. Despite improved technique, the increases in strength achieved by the training group were significantly greater than, and more than double those achieved by the control group on all tests.

Progressive resistance training resulted in a significant increase in occupational lifting strength. The training group increased 23%, while the control group increased 10% in maximal box lifting strength, even though box lifting was not utilised as a progressive resistance training exercise. This reflects the effectiveness of a training programme specifically designed to train muscles instrumental to a particular activity. The initial portion of the box lift (floor to knuckle height) was similar in technique to the deadlift, while the second portion of the lift (knuckle to shoulder height) was a combination of the high pull and bench press exercises. Sharp and Legg (1988b) observed a 6% increase in box lifting strength following repetitive box lifting with no progressive increase in load lifted, while Asfour et al. (1985) found a 55% increase in box lifting strength from floor to 127 cm with progressive resistance box lifting training. The 55% increase is much greater than that observed in the present study and may be due to the use of the same movement for testing and training, or to a subject group with a lower initial level of strength. Progressive resistance box lifting is the most effective way to improve box lifting capacity, but not all occupational tasks requiring physical strength lend themselves to task specific training. For

these tasks the specific muscle groups involved can be strengthened with progressive resistance exercises.

3.5 Ten minute repetitive lifting task.

The progressive resistance training group increased the number of lifts completed in ten minutes significantly more than the control group who did not train. The mean change in the control group was -2.8 lifts (-2.4%), while the training group improved by an average of 13.4 lifts or 18.8%. Most of the training group increase in 10 min lift task performance (15% of 18.8%) was accomplished by the 8th week of training. Sharp and Legg (1988b) reported a 26% increase in repetitive lifting performance following 4 weeks of task specific training, while Genaidy et al. (1989) reported a twofold increase in endurance time on a carrying task following 2-1/2 weeks of task specific training. The improvements in task performance resulting from progressive resistance training are more modest than those following task specific training, however, progressive resistance training is more accessible than task specific training for many occupations. Progressive resistance training can be performed on a set schedule, unlike task specific exercise performed only occasionally during a shift. Where it is not practical to train by performing the task, such as in fire fighting or emergency medicine, progressive resistance training can be used to prepare for and improve task performance. Careful evaluation of the job requirements must be made to select the appropriate training exercises. This study does not provide information regarding occupational injury rates, however, previous data

indicate that stronger employees would be expected to incur fewer overuse/overload injuries (Cady et al. 1985; Doolittle and Kaiyala 1986).

Measurements made during the 10 min lift test are listed in table 3. The percentage change from pre to post training in oxygen uptake during the 10 minute lift task in the training group was 2.0%, which was significantly different from the control group change of -7.1%. The training group utilized approximately the same amount of oxygen to perform more work, while the control group decreased slightly in both the amount of oxygen used and work done. Training did not affect the percentage of VO_2max utilised during the 10 min lift task as there was no significant difference between groups in the change in percentage VO_2max from pre- to post training. Both groups experienced high blood lactate levels following performance of the 10 min lift task, but the groups were not significantly different from each other, and training had no effect on this measurement.

Table 4 contains the correlations between profiling measures and 10 min lift task performance for pre-training, post training and post minus pre-training measurements. 10 min lift performance was significantly correlated with all measures of strength before and after training, with the exception of maximum box lift after training. When change scores were analysed, the change in 10 min lift performance from pre- to post training was significantly correlated with the change in bench press, deadlift and combined strength. Bench press was most highly correlated with 10 min lift performance, which suggests that upper body strength is one of the limiting

factors in performing the 10 min lift task. Fat free mass and body weight were significantly correlated with 10 min lift performance before and after training, but the change in these measures from pre- to post training were not. Maximal oxygen uptake was not significantly correlated with 10 min lift task performance at any time, indicating that strength and body size were more important than aerobic capacity for 10 min lift task performance.

4. Conclusions

1. When it is not practical to train by performing an occupational task, progressive resistance training can be used to improve task performance.
2. Progressive resistance training can be used to increase maximal occupational lifting strength.

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Table 1. Body composition of control (CT, n=7) and training groups (TR, n=18) before and after training (Mean ± SD)

		Pre-training	Post training	% Change
Weight (kg)	CT	76.4 ± 12.8	77.0 ± 14.1	0.4
	TR	73.3 ± 10.7	77.0 ± 13.1	4.4[1]
Fat free mass	CT	65.4 ± 10.0	66.3 ± 9.7	1.5
(kg)	TR	61.9 ± 7.3	64.4 ± 8.1	4.1[1]
Body fat (%)	CT	11.0 ± 5.5	10.7 ± 7.3	-9.4
	TR	11.4 ± 5.0	12.5 ± 6.3	6.7

[1] Significantly greater than control group in percent change pre- to post training ($p<.05$).

Table 2. Strength determinations for training (TR, n=18) and control (CT, n=7) groups over time.

		Pre training	Week 4	Week 8	Post training	%Δ
Bench Press (kg)	CT	79.0 ± 17.4	79.0 ± 16.0	78.0 ± 16.8	77.1 ± 14.1	-1.6
	TR	76.5 ± 14.5	82.6 ± 16.1	87.8 ± 17.0	92.4 ± 16.1	21.3[1]
Deadlift (kg)	CT	124.4 ± 23.7	134.1 ± 21.4	132.8 ± 22.2	134.0 ± 21.5	8.9
	TR	128.9 ± 18.2	141.1 ± 19.7	150.6 ± 19.2	153.6 ± 20.2	19.8[1]
Squat (kg)	CT	102.5 ± 25.2	108.4 ± 28.4	106.3 ± 33.2	111.3 ± 28.5	8.4
	TR	104.4 ± 21.7	118.8 ± 23.9	131.5 ± 17.8	138.5 ± 21.3	34.6[1]
Combined[2] (kg)	CT	305.9 ± 62.6	321.5 ± 64.1	317.2 ± 68.3	322.5 ± 60.5	5.9
	TR	309.9 ± 49.7	342.5 ± 54.3	370.0 ± 47.7	384.6 ± 52.8	24.7[1]
Box Lift (kg)	CT	71.9 ± 8.2	78.1 ± 12.8	78.0 ± 12.3	79.1 ± 9.3	10.1
	TR	73.0 ± 10.3	79.7 ± 10.2	84.5 ± 11.4	89.0 ± 10.3	22.8[1]

[1]Significantly greater than control group ($p<.05$) in percentage change pre- to post training.

[2]Combined=bench press + deadlift + squat.

Table 3. Results of 10 min lift task performance over time for the control (CT, n=7) and training (TR, n=18) groups (mean ± SD)

		Pre-training	Week 4	Week 8	Post training	% Change
Lifts completed	CT	84.9 ± 26.1	85.4 ± 28.5	83.9 ± 27.4	82.0 ± 21.7	-2.4 ± 6.3
	TR	79.1 ± 17.4	85.7 ± 20.7	91.3 ± 17.8	92.4 ± 17.6	18.8 ± 14.8
$\dot{V}o_2max$ ($ml \cdot kg \cdot min^{-1}$)[4]	CT	47.0 ± 7.2	43.7 ± 7.9	43.3 ± 7.3	44.3 ± 8.7	-7.1 ± 11.8
	TR	45.1 ± 6.0	43.6 ± 4.9	43.9 ± 6.7	46.0 ± 6.0	2.0 ± 6.7[1]
% $\dot{V}o_2max$[2,4]	CT	87.7 ± 11.3	88.0 ± 12.4	89.0 ± 13.0	90.1 ± 14.2	2.4 ± 11.0
	TR	84.9 ± 6.5	86.6 ± 7.1	NA	93.8 ± 8.9	8.9 ± 8.7
Heart rate[4] ($beats \cdot min^{-1}$)	CT	171.0 ± 9.3	170.0 ± 12.6	171.8 ± 12.0	169.6 ± 12.1	-4.4 ± 9.9
	TR	179.1 ± 6.8	180.0 ± 6.1	180.5 ± 6.9	182.8 ± 5.8	2.1 ± 2.3[1]
Blood lactate[3] ($mmoles \cdot l^{-1}$)	CT	11.0 ± 3.8	NA	NA	10.0 ± 4.7	7.8 ± 22.1
	TR	9.4 ± 2.2	NA	NA	10.7 ± 2.5	20.2 ± 34.8
Height of lift (cm)	CT	140.7 ± 3.9				
	TR	137.7 ± 5.8				

[1] Significant difference between groups ($p<.05$).

[2] Percentage of repetitive lifting $\dot{V}o_2max$ utilised during 10 min lift test.

[3] Represents change in blood lactate from resting to 5 min after performance of the 10 min lift test.

[4] Represents mean of values collected at 30 sec intervals from time 0:30 to 10:00 during 10 min lift task.

Table 4. Correlation of 10 min lift performance with profiling variables measured before and after training and the change in performance correlated with the change in profiling variables from pre to post training (n=25).

	Pre-Training	Post Training	Pre-Post Change
Box lift	0.52*	0.34	0.32
Bench press	0.77*	0.74*	0.61*
Squat	0.56*	0.65*	0.19
Deadlift	0.67*	0.62*	0.57*
Combined[1]	0.71*	0.71*	0.53*
Fat free mass	0.68*	0.64*	0.23
Body mass	0.64*	0.59*	0.24
$\dot{V}O_2max$ ($ml \cdot kg \cdot min^{-1}$)	0.06	-0.32	0.19

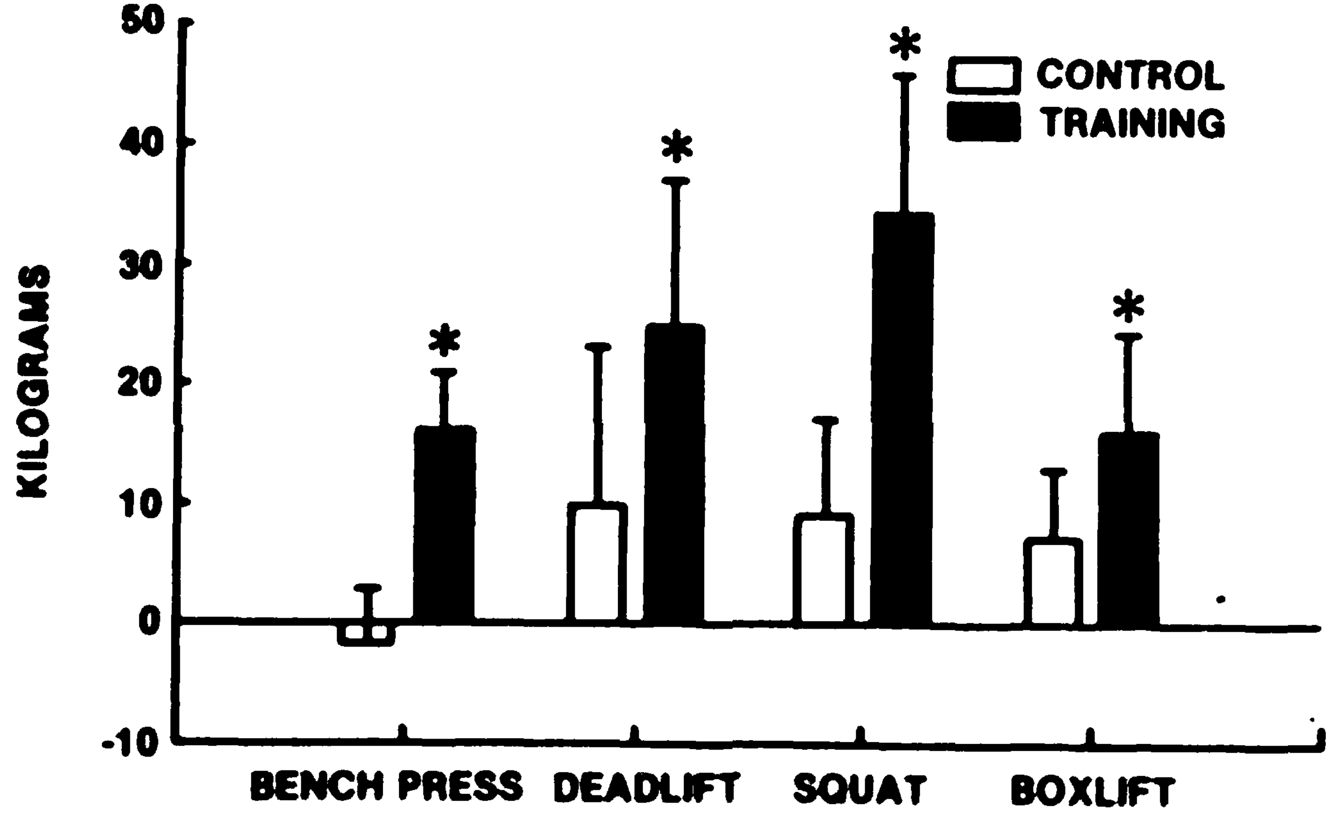
* ($p<.01$)

[1]Total=Bench press + deadlift + squat

Figure 1. Pre- to post training change in strength for the control and training groups. '*' indicates signficant difference (p<.05) from control group.

HUMAN RESEARCH

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.



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